MONOGRAPH SERIES

ON

'ENGINEERING OF PHOTOSYNTHETIC SYSTEMS'

(Volume 2)

'ENERGY PLANTATIONS' — A CASE STUDY FOR THE COROMANDEL LITTORAL

C. V. Seshadri
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(i)

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PREFACE

Consider the casuarina tree. It grows all over the Deccan Peninsula ; in particular it grows on ocean beaches all over the South. It will grow without much attention or much water. It is used for building huts and pandals ; it is widely used as scaffolding ; it is used for fuel-wood. Its leaves and twigs are gathered by village women for fuel. It is not eaten by goats or cattle. It fixes nitrogen from the atmosphere and adds it to the soil.

This study is about intense cultivation of casuarina (Latin : *Casuarina equisetifolia*) for generating 100MWe (installed 160MWe) in a power plant. Using the cultural practices of four different areas in Tamil Nadu, Costs and Energy calculations have been carried out. The calculations account for continuous, rotational harvesting.

This study would not have been possible without the active and enthusiastic assistance of many people. These people are listed separately. A few of them deserve special mention here. Dr. S. R. Sreerangaswamy, Principal, Krishi Vigyan Kendra, Pondicherry, now at TNAU, Coimbatore, Sri P. M. Muthukumarappa and Sri S. P. Ambrose, I.A.S., ex-Chairman, TNEB, have assisted us greatly with detailed information.

Sri V. Vasanth, IV Year Mechanical student at IIT/Madras has worked for this Centre, part-time, and in fact is co-author of this study. The Centre is grateful for his assistance.

Sri M. V. Murugappan, Member, Governing Body, MCRC, has been a constant source of encouragement and support.

C. V. Seshadri

1978, May.

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(1) Dr. S. R. Sreerangaswamy.

(2) Sri P. M. Muthukumarappa, M.Sc., 'Multigro' Farm, Madurantakam.

(3) Sri S. P. Ambrose, I.A.S.

(4) Sri Kumaraswamy, Polambakkam.

(5) Sri Jayarama Reddiar, Polambakkam.

(6) Sri S. K. Mani, Injambakkam.

(7) Sri A. Sekhar Anandam, B.Sc. (Ag.).

We gratefully acknowledge the help and assistance of these people. The results and conclusions are solely our responsibility.

SUMMARY OF CONCLUSIONS

1. Using cultural practices in Pondicherry, Madurantakam, Injambakkam and Forest Department areas, Costs and Energy analysis have been undertaken for setting up a 160 MWe (100 MWe average) power plant burning fuel-wood from the casuarina tree.

2. The Pondicherry Method using 10,000 trees/ha and yielding upto 300 tonnes/ha 4 years seems to be the best for this purpose. 1.1 square kilometres are required per Megawatt. The plantation will employ about 11,000 agricultural labourers.

3. Using this method and depending upon certain investment decisions, the plantation will pay back all capital and other costs in periods varying from 5-30 years. At the end of the larger periods, land becomes wholly owned by the plantation. The plantation can replace coal burnt power.

4. Other methods have varied degrees of success or do not result in viable commercial ventures.

5. The energy returns are always favourable. Ecologically these plantations are far more desirable than present thermal power plants.

6. The use of intensive forestry of casuarina renders many benefits to the soil. Some recommendations are given for improving certain aspects of forestry practice.

7. These plantations offer a way to generate small amounts of decentralized power for rural use.

ENERGY PLANTATIONS — A Case Study for the Coromandel Littoral

SECTION. 1: WHAT IS AN ENERGY PLANTATION?

A typical definition may run as follows: [a] An Energy Plantation is one that grows plant materials for their fuel value. This fuel may be the plant material itself or processed material such as charcoal; gaseous or liquid fuels such as methanol or fermentation products such as ethyl alcohol. The land to be used for this purpose is usually considered cultivable waste and land that is unavailable for conventional agriculture. [b] Though various grasses, shrubs and other plants have been considered in the past as Energy-Plants, this study restricts itself to the systematic cultivation, for the purpose of power generation, of quick growing fuel wood trees, e.g., *Casuarina equisetifolia* along the sandy tracts of the Eastern coast line. Since most of our information is from Tamil Nadu, this case study applies to this state in particular.

Notes: (a) For references see section on bibliography.

(b) In fact, energy plantations can be used for reclaiming land for agriculture.

BIBLIOGRAPHY AND NOTES FOR SECTION 1.

The following references are recommended for an over view :

Ref: 1. 'Chemtech' (p. 275-284, May '73) George C. Szego and Clinton C. Kemp. " Energy forests and fuel plantations "--This reference has been widely quoted and is probably the best general introduction.

Ref: 2. ' Solar Energy ' : A U. K. Assessment : U. K. Section of ISES, May 1976. (p. 274-275). Considers the general background to Energy Plantation besides quoting reference 1, it has a survey of other sources also.

Ref: 3. 'Invention Intelligence' (NRDC-Ring Road, New Delhi), Jan.-Feb. '77 ' Technology for the Masses '-Special Number (p. 79-87), B. D. Patil and P. S. Pathak : ' Energy Plantations and Silvi-pastoral systems of Rural Areas '. This is one of the best technical papers in the Indian context-highly recommended.

Ref: 4. R. E. Inman (The MITRE Corporation, Mclean, Virginia, USA) in 'Sharing the Sun ' - Solar Technology in the Seventies - Vol. 7, p. 100 American Section of ISES, Winnipeg - 1976, and ' European Seminar on Biological Solar Energy Conversion Systems ' May '77, Grenoble France, p. 20.

Both these are essentially the same article and discuss prices of generating electricity from silviculture Energy Plantations. Also a good discussion of land usages, harvest, etc., from cost-view point.

Ref: 5. Nanu B. Amin in 'The Economic Times' Friday Aug, 5, '77, both editions, New Delhi, Bombay, ' Solar Energy through Photosynthesis '. Repeats reference 1 quite a bit for popular consumption. Discusses the need for Energy Plantations in Gujarat due to the distance from coal fields.

Ref: 6. Minaz Merchant : 'Power from Trees'. ('The Times of India' - Oct. 6, 1977).

Ref: 7. Kumar Ketkar: 'Plant a tree for Energy' ('The Economic Times" Oct. 30, '77) Both these articles reflect Mr. Iqbal Krishna Bharati's views on using trees for generating power. Good newspaper publicity.

Ref: 8. 'The Indian Express', Madras, Oct. 6, '77. Quotes U.N. agencies on cultivation of firewood trees systematically as an Energy Plantation.

Ref: 9. Seminar proceedings of NPC: 'Industrial Applications of Solar Energy', Madras, June 4, 1975 (National Productivity Council, New Delhi-3) V. G. Bhide, (p. 60-100) discuss power generation using Energy Plantations - arrives at prices. etc.

Ref: 10. 'Energy for Survival'-Wilson Clark (Allied Publishers, New Delhi, 1974) Arguments by a committed high-technology hater; gives areas required for power generation through Energy Plantations.

SECTION. 2: WHY ENERGY PLANTATIONS?

This section is a brief statement of the advantages and disadvantages of using Energy Plantations for power generation. The general advantages are :--

(1) the fuel resource is renewable.
(2) transportation is minimal.
(3) the technology of growth and harvest is well known.
(4) they provide ecologically safe fuels.

The specific advantages for '*casuarina*' plantations are :

(a) they are quick growing trees.
(b) they are high yielding.
(c) they are well adapted to the coastal region.
(d) they fix nitrogen from the atmosphere.

(e) they permit intercropping with ease.
(f) the plantation is a labour-intensive operation.
(g) there is sufficient area available for such Plantations in this region.

The disadvantages are that :

(a) large land areas are needed.
(b) the Energy Plantation may compete with other crops for land.
(c) the power plant designs may change for the new fuel.

Some justification for the above points is given here. For exhaustive notes and references, the reader is referred to the Bibliography.

(a) The fuel resource is renewable since it relies on short-term bioconversion of solar energy. Energy Plantations use the sun's energy over a period of 4-8 years on a renewable basis whereas fossil fuels are renewable, (if such a word can be used here) over periods of millions of years (50 million for oil). The efficiency of conversion is usually considered te be between 0.6 % to 1% of incoming solar energy, though figures upto 2.5% have been quoted.

(b) Though pit-head power plants have been advocated recently, most power plants in the South are receiving coal from Eastern and Central India. At Neyveli, lignite is used for thermal power generation, otherwise all coal has to travel long distances. This has three disadvantages: the substantial fuel consumed for transportation, the pollution due to such fuel, either as combustion products or as spills and leaks, uncertainty of deliveries in times of labour-trouble.

(c) Compared to newer energy-technologies, e.g. nuclear, non-biomass solar, or even the modern mining of fossil fuels, cultivation techniques are age-old, suited to an agricultural economy and can be labour-intensive.

(d) Ecologically, fossil fuels as presently used, hold out a promise of a future of increasing calamity. Carbon dioxide, thermal energy, sulphur dioxide and nitrogen oxides are pollutants of immense damage-potential. This is after the fuel is burned. The mining of coal and oil is fraught with its own pollution hazards. Compared to these problems, fuel wood when burnt emits no sulphur dioxide. The thermal energy and carbon balance is such that inputs and outputs are the same over the period of growth and harvest. Thus the

carbon dioxide of the atmosphere does not rise above equilibrium levels in the long run. This is also true of the energy capture from the surroundings. An important advantage of the ash from fuel-wood (as opposed to fly-ash etc.) is that it can be used as a fertilizer. Ecologically speaking, the only disadvantage of Energy Plantations is that there may be forest fires.

The specific advantages of *Casuarina equisetifolia* as an energy crop are also dealt with in the next section on silvicultural practices. The usual practice on the coastal belt is to plant seedlings on the sandy shore-tracts under no-till conditions, water the plants by hand for a year or so and then to harvest the whole tree after 5/7 years. After the first year to the penultimate year, the tree also yields loppings of about 3–5 tonnes/ha-year. Thus yield adaptability and cultural practices are well known. In fact casuarina grows as fuel-wood all over the Deccan. The plant fixes nitrogen through symbiotic bacteria and adds fertility to the soil. Though eucalyptus varieties are better yielders, their wood is invariably committed for rayon-pulp and is usually unavailable for fuel. Hence the choice of casuarina. There are also hybrid varieties available.

There have been many improvements in casuarina forestry including intercropping with groundnut, sorghum etc. and mechanisation of operations, though traditionally it is a labour-intensive cultivation with very little attention given to the crop after the first year. Usually the village women sweep the ground under the trees and collect the sweepings for fuel and thus obtain enough for their domestic needs.

The large areas that are needed for Energy Plantations, typically about 3-8 square kilometres per megawatt of power, seems to be a real disadvantage when viewed in isolation. However some idea of the area available in Tamilnadu may be helpful to place these figures in perspective: Excluding forest areas and conventional agricultural areas (net area sown), there are about 34,000 square kilometres of fallow, waste and barren land available in the state. Thus the Energy Plantation concept can be tried in large areas, if found feasible. These Plantations will also not compete with food and cash crops for land.

As for changing the boiler design to adapt to the new fuel, the changes are only in the grating and recuperator design. The maximum flame temperature of wood-fuel is also lower than coal, hence the heat transfer characteristics will be altered. However wood,

straw and residue burning power plants are not new in concept. There are 230 such plants, operating in North America, on chipped or hogged wood. Bagasse burning plants are not unusual even in India and a large plant has been commissioned in the Philippines to burn coconut wastes. In Philippines at Mindanao, a power corporation has converted over 3,000 ha of grass land into an Energy Plantation with "IPIL-IPIL"-*Leucaena-leucocephala*, a tropical legume which will be converted into charcoal for industrial use; the foliage serves as nutritious forage for animal and rich organic manure. (See also Section 4: Cost and Energy Analysis for a comparison of casuarina and ipil-ipil performance.) Thus designs for burning agricultural residues and wood are available.

In any discussion of Energy Plantations, a proper perspective must be maintained when looking at the advantages and disadvantages. Technologically, they use only renewable resources for harnessing energy in usable forms. At the end of this study, it is hoped to show that the energy efficiency of such a process is higher than the conventional ones. Ecologically they are a much sounder investment than the burning of fossil fuels. In fact afforestation and harvest in a systematic manner will lead to long term benefits by way of soil and moisture conservation, in addition to providing local employment which brings us to what is probably the most important talking point in favour of Energy Plantations. They offer a way of generating small amounts of power in a decentralized manner such that transmission and distribution losses are cut down to an absolute minimum. In this sense an Energy Plantation-power plant is more appropriate in the post-industrial context. Energy Plantations have a definite edge on energy sources in a decentralised, rural-biased economy where capital investment per work place needs to be low and land utilisation for traditional skills needs to be high.

BIBLIOGRAPHY AND NOTES FOR SECTION 2.

In addition to all the references under Section 1, a few references are discussed here under the various points of this section.

1. **Renewable resource:** The figure for photosynthetic efficiency comes from reference 2, of Section 1, p. 275. The 'Invention Intelligence' (ref. 3) article makes a good case out for silvi-pastoral or multistoried Energy Plantations for good leaf coverage of the ground to raise the photosynthetic efficiency.

2. **Transportation** : Using an American figure, given by Ref. 10, p. 152, 156, the energy in coal (i.e. obtained on burning), the energy needed to transport it 1,000 miles (1,600 km) by rail and the energy needed to mine it and bring it to the pithead can be reduced to coal equivalents.

Some ratios : Energy in coal/energy needed to produce it = 150

Energy in coal/energy needed to transport 1,600 km. = 40

$\therefore$ Total energy in coal/Total energy to deliver from lode to plant in S. India is roughly 32.

Another way of saying the same thing is that if 1,000 tonnes of high quality coal are mined and transported 1,600 km, 32 tonnes are being rejected into the atmosphere in the form of waste gases and heat. Thus in addition to the money spent on transportation and mining of coal, it is an energy - intensive, wasteful process.

4. **Ecologically Safe Fuels** : Ref. 11. Gerard. M. Crawley : 'Energy' (McMillan Publishers, New York) 1975 p. 101 has a discussion of the advantages of Energy Plantations. Also see Ref. 10, Section 1. Though thermal power plants burning fossil fuels are not the sole polluters of the environment, what is said below is applicable to them in large measure.

(a) Coal miners suffer quite commonly from black lung disease and other respiratory problems.

(b) Underground mining is often accompanied by drainage of unwanted chemicals into streams and the collapse of land near old mines.

(c) The effect of CO_2 release by burning coal can raise the earth's temperature by the green-house effect. Since this Carbon dioxide was fixed anywhere upto 250 million years ago, its sudden release into the atmosphere is a harmful source of pollution.

(d) The thermal power plant usually releases 6% of the energy in the coal as heat into the atmosphere; again this is a sudden release when compared to the geologic span of life of the coal. In thermodynamic language the exothermic heat of combustion (exergonic heat) does not balance the endothermic (endergonic) fixation of solar energy and the energy of synthesis of cell-matter. Such imbalances do not exist in Energy Plantations.

(e) Sulphur dioxide, nitrogen oxide, carbon monoxide and elements such as beryllium, nickel, cadmium are released into the atmosphere from fossil fuel plants. Energy Plantations do not emit sulphur dioxide when burnt.

(f) The ash from fossil fuels is not a fertilizer, whereas wood-ash is. Therefore it is not a pollutant.

(g) Probably the most disturbing indictment of coal powered plants (see Ref: 12. 'The Times of India', August 18, 1977) is that such plants release 400 times more radioactivity into the atmosphere than nuclear powered plants. Thus their neighbourhoods are unsafe. The fly ash contains Radium 226, a long-lived, β emitter (see Ref: 13. Raja Ramanna, 'Blitz'—Republic Day Special, 1978).

Specific Advantages

The following references have been used here. Most of the references led us to notes, personal conversations and observations :

Ref: 14. Dr. S. R. Sreerangaswamy, Principal, Krishi Vigyan Kendra, Pondicherry. 605 010.

Ref: 15. Sri P. M. Muthukumarappa, 'Multigro' Farm, Polambakkam-Madurantakam (T. N)

Ref: 16. Sri Kumaraswamy, Polambakkam, Madurantakam (T. N)

Ref: 17. Sri Jayarama Reddiar, Polambakkam, Madurantakam (T. N)

Ref: 18. Sri S. K. Mani, Injambakkam, Madras. 600 041. (T. N)

Ref: 19. Sri Jim devries and Jos, Auroville (T. N)

Ref: 20. Tamilnadu Forest Statistics ('75-'76), Planning and Statistical cell, Office of the Chief Conservator of Forests, Madras. 600 006.

Ref: 21. W. D. P. Stewart, 'Nitrogen fixation in Plants' (U. of London-1966). p 27, 128.

Since Section 3. deals with silviculture of casuarina, all tables and details are given there.

The general disadvantages of energy plantations are treated most completely by Ref: 22. E. E. Robertson, "Perpetually renewable biomass prospects". "Sharing the Sun" Vol. 7. American section, ISES, 1976. page 163. However most of the points are not applicable to India and hence are not disadvantages. The land is not used for conventional agriculture at present and therefore does not compete with food crops etc. Also he argues on a capital-intensive basis whereas biomass plantations are being advocated here for their labour-intensive character. Also it is not true that hybrid varieties will never be found. On the whole while ecological arguments e.g. against monocultures etc. are valid, the Energy Plantations here are not new types of fuel woods but fully adapted varieties.

Ref: 23 "The Hindu" dt. 12-12-77 Madras. "Power from coconut wastes" reports on power plants designed to fire coconut wastes.

Ref: 24 "Energy Update" November 77, published by Tata Energy Research Institute, Documentation centre, Bombay, 400 023, p. 5 and **Publication** from National Academy of Sciences, National Research Council, 2101, Constitution Avenue, Washington, DC. 20418-USA- quotes IPIL-IPIL *Leucaena leucocephala* as an Energy Plantation crop. The plant reaches a height of 13 metres in 2 years. 50 to 60 ha of this crop can produce 500 KW of electricity. This plant can be used to revegetate tropical hill slopes and provide wind breaks, shades and ornamentation.

SECTION. 3: EXISTING SILVICULTURE PRACTICES

Casuarina is a large evergreen tree, that looks like a feathery conifer, and is a hardy plant well adapted to coastal areas. Allowed to grow, it can reach a height of 15 metres and a trunk diameter of 30 cm. It belongs to the family Casuarinaceae, originating from Australasia.

Culturally, it is useful for afforesting sandy beaches and shifting dunes along the coast. There is a constant demand for casuarina as a valuable source of fuel and building and scaffolding material. In fact it may be well worth undertaking systematic plantation of casuarina for this purpose alone. As hut building material, it usually has a life of 3-5 years in the coastal belt. *Casuarina equisetifolia* in association with a micro-organism *(Actinomycetes)* fixes the nitrogen of the atmosphere in the soil. The amount so fixed, about 80 kg/ha year, is available then for other crops. Soyabean, a legume crop, fixes about 94 kg/ha year, so the figure for casuarina is quite appreciable.

In Tamilnadu casuarina is grown under varied conditions: (a) in garden lands with Groundnut, Maize, Sorghum etc. as intercrops. (b) in dry lands, (c) in sub-marginal lands with little after-care and (d) in sandy coastal belts with minimum cultural operations. The rotation period and the yield varies with the mode of cultivation. The usual rotation cycle ranges from 4-8 years. Casuarina yields upto 250 tonnes/ha in four years in Pondicherry. In Thana, casuarina grows well and has recorded a yield upto 285 tonnes/ha in four years under irrigated conditions and fertilization with urea and cowdung in the first year, with a population of 3,000 plants/ha. Some trees grow to a height of 13 metres with 20 cm trunk diameter, weighing 95 kg each. Casuarina yield in sandy coastal belts is 65 tonnes/ha in five years. The percentage of moisture in freshly cut casuarina timber is 30 and 20 in 4 year old and 7 year old trees respectively.

Cultural practices for casuarina varies with place in this region. The variety prevalent in our state is *Casuarina equisetifolia;* however new hybrid varieties are also under trial.

At Madurantakam taluk in Chengalpattu district, casuarina is grown under irrigated conditions and is harvested in 5 years. Casuarina nursery involves two stages. The seeds of casuarina are first sown in well prepared and manured beds of standard size 10 M x 10 M and watered. The seeds germinate within a fortnight. When the plants reach a height of 8-10 cm, they are pulled out and transplanted closely into the second nursery beds of similar dimensions and preparations and are watered regularly. The seedlings stay in the second nursery beds till they attain a height of 30-50 cm in 4—6 months, and are ready for transplantation into the main fields.

The main field is well prepared with tractor driven disc ploughs, harrows and cultivators. Bunds are then formed along contour and trimmed and plastered, by human labour. Contour bunds aid moisture conservation and prevent soil erosion. Aligning and stacking is done at an espacement of 1 metre by 1 metre and 30 cm^3 pits are excavated allowing a stand of 10,000 plants in a hectare. The seedlings are planted in pits and are pot watered daily by women, for the first month and later irrigated at wider intervals during the first year. The first intercultivation, weeding and hand hoeing is done, three months after transplantation during which time suitable inter-cropping with groundnut, maize, ragi sorghum etc. is done. By intercropping practice casuarina enjoys fertilization, irrigation and other cultural operations done for the intercrop. As monoculture casuarina is fertilized with either urea alone at 125 kg/ha or urea at 60 kg, Super phosphate 125 kg and Muriate of Potash 60 kg/ha during the third month of growth.

During the second year the plants are watered once every fortnight in the hot summer months. Hoeing and weeding and pruning up of the twigs are the principal cultural activity in the second year. The trees are pruned with bill hooks by men climbing up the trees.

During the next two years only hoeing and weeding and pruning is done. The plants are watered at fortnightly intervals during hot summer weather. The trees grow to a sufficient height and attain a reasonable girth and are ready for harvest in the fifth year. The trees are felled, cut and stacked into standard lot size of 3M x 1M x 0.6M. The chief mode of transport is by lorries. The yield of timber is 125 tonnes/ha. The root stump which is a difficult part to be removed, is taken care of by the local dwellers for their fuel needs.

At Pondicherry, under irrigated conditions casuarina yields 250 tonnes per hectare in four years. In this region for casuarina plantation, the main field is thoroughly prepared with animal drawn country ploughs alone and 30 cm^3 pits are excavated at 1M x 1M spacing in a "square" pattern allowing 10,000 plants/ha, and well grown seedlings of 30-50 cm are planted. The seedlings are pot watered by women, daily, during the first month. There is no fertilizer application in this tract. The plantation is watered in the subsequent years only during hot summer months at fortnightly intervals. Hoeing and weeding and pruning are the other cultural operations. The trees are cut at the

end of the fourth year and are stacked in standard lot size, and transported to the market in lorries. Intercrops are grown during the first year of growth. **At Injambakkam**, a village in Chengalpattu district, lining the eastern coast, casuarina is grown in sandy tracts with minimum cultural practices. The mainfield is ploughed initially and pits of 30 cm^3 are dug in the sand at 2M x 2M spacing allowing a total of 2500 plants in a hectare in a "square" pattern. Well grown seedlings of 30-50 cm height are planted in the pits and are pot watered daily, during the summer months of the first year, as the water holding capacity of sand is very poor. During the next three years only pruning is done. The trees are felled in the fifth year, cut, stacked and transported by lorries. The yield is 65 tonnes/ha.

The Tamilnadu Forest Department adopts a different procedure for casuarina cultivation. Well grown seedlings of 30-50 cm height are planted in cleared and well dug pits of 30 cm^3, at an espacement of 2.5M x 2.5M maintaining 1600 plants per hectare. The seedlings are pot watered till they establish themselves. The watering is restricted to a maximum of 150 days from planting. Replacement of casualty is done during the first year and weeding around the plants is also done. During the second year soil working with hand-hoes is done and the 'backward' plants alone are watered. In the fourth year the plants are pruned and the pruned materials (loppings) are disposed in public auction. The trees are harvested in the seventh year, they are felled by strips, cut and stacked in lots of 3M x 1M x 0.6M. The estimated average yield is 65 tonnes/ha in seven years.

Suggestions for future silviculture Practices :

(a) Ratooning of casuarina, which yields one year ahead of regular plantation may be taken up. But only the first ratoons are economical and subsequent ratoons will yield poorly.

(b) The regular planting pattern is the "Square planting". Instead "Hexagonal planting" pattern which accommodates 16.28% more plants in one hectare than in the "Square planting", should be adapted for increased bio-mass yield. Here the spacing between plants is unaltered.

(c) The efficiency of the nodulated 'N' fixing bacteria can be enhanced by the application of micro nutrient elements like Iron and Molybdenum and trace elements as Cobalt.

(d) "Mechanical shock" to the trees, improves the growth rate of casuarina, as was observed personally.

(e) Hybrid casuarina which yield in three years or less should be propagated widely.

(f) Some genetic modifications to increase the photosynthetic efficiency can be made for increased bio-mass production.

(g) Bio-mass yield can be increased through engineering practices, *e.g.* by reducing the effects of photo respiration using higher carbondioxide concentration and lower oxygen concentration.

Some of the Research programmes under the State Forest Department are listed below:

(i) to study the suitability of casuarina in alkaline area, at Vandalur Research Centre.

(ii) Some studies to find out the difference in yield of female and male trees and air layering of *Casuarina jungheeniana*, at Markanam Research Centre.

(iii) Some comparative studies in the yields of *Casuarina equisetifolia*, and *Casuarina jungheeniana*, at Sholapuram Research Centre.

(iv) Experiments are conducted to study whether sand dunes can be stabilised by planting *Casuarina equisetifolia*, at Rameswaram Research Centre.

At Krishi Vigyan Kendra, Pondicherry, species selection studies are being carried on.

There is a vast scope for Energy Plantations in Tamilnadu. Split up figures of area available for casuarina plantations is furnished here :—

(a)	Barren & uncultivable land	- 7,020 sq.km
(b)	Cultivable waste	- 4,370 sq.km
(c)	Current fallows	- 17,310 sq.km
(d)	Other fallows	- 5,990 sq.km

—amounting to a total of 34,690 sq. km in favour of Energy Plantations. These areas do not compete with the land for food production. Though these areas are not available in a block for Energy Plantations, small blocks within a radius of 50 kms, are available for feeding smaller decentralised power plants at vantage points continuously thus minimising transmission and distribution losses—a major disadvantage of larger centralised power plants.

Casuarina, a hardy plant, well adapted to sandy coastal belts has also a bright future along the 600 km long, coast of Tamilnadu. It will be a labour intensive and energy saving scheme.

Many of the details are elaborately dealt with in Cost and Energy analysis.

BIBLIOGRAPHY AND NOTES FOR SECTION 3.

Existing silvicultural practices and suggestions for future silviculture practices :

For casuarina's silvicultural characteristics and cultural practices adapted by Forest Department refer :—

Ref : 25 Tamilnadu State Forest Department's manuscript. References 21 & 14, deal with the Nitrogen fixation by casuarina and its adaptability to coastal belt.

Ref : 26 "Science Today", February 1978, publisher Bennett, Coleman & co. Ltd., Bombay 400 067, p. 40-44. "Let's get to know our trees", "Trees of coastal region" by S. R. Amladi, describes in brief the silvicultural characteristics of *Casuarina equisetifolia* and quotes it as the "best fire wood" in the world, and appreciates its efficiency.

Ref : 27 M/s R. P. Shroff & Associates, Industrial Consultants & Energy Engineers, 8/17, Wadia Street, Tardeo, Bombay-400 034, quotes the yield of casuarina under irrigated condition in Thana, Bombay.

Ref: 14 Describes in detail the total yield of casuarina which included loppings forming 20–30% and roots forming 3-5% of total timber yield in a field study of a rainfed crop. The 30% dryage of 4 year old felling and 20% dryage of 7 year old felling are also discussed and also the cultural practices prevailing in Pondicherry.

In the field study the following were recorded :- Felling at Pillayar-kuppam (Pondicherry) on 22-12-77. The stand in the plantation was one tree per Sq. Meter at 25 trees per 5.0 M x 5.0 M (25 Sq. M). A scoring of the trees, for growth at the time of felling indicated following frequencies for growth.

Frequencies in 5 samples :

Sample / Rating :	1	2	3	4	5	Total	%
Large -	11	10	6	11	18	56	29.5
Medium -	18	16	16	18	26	94	49.5
Small -	6	8	8	8	10	40	21.0
Total	35	34	30	37	54	190	

In practice after felling is done by cutting, the lateral roots and the main roots snapped off. After that the tree is cleared of the loppings (i. e. the side branches along with leaves). Then each tree is cut/sized into 9 to 12 pieces according to height and staked/logged in heaps for sales.

Treewise data of a 25 Sq. M plot.

(Six trees were missing)

Tree No.	Height in Metres	Girth in cm 15 cm above ground and at mid level		Weight of tree with loppings (Kg)
		Base	middle	
1	8.5	19.0	11.0	11.0
2	9.6	25.0	12.0	25.5
3	10.8	25.0	16.0	38.0
4	9.0	20.0	10.0	11.5
5	11.0	21.0	11.0	18.3
6	7.5	12.0	9.0	4.0
7	8.1	12.0	9.0	6.5
8	6.0	16.0	10.0	7.5
9	10.1	18.0	10.0	11.0
10	8.1	20.0	12.0	14.5
11	11 0	19.0	12.0	28.5
12	5.6	14.5	9.0	4.0
13	7.0	15.0	9.5	7.0
14	11.4	25.0	17.0	31.5
15	12.3	30.0	19.0	46.0
16	16.1	39.0	20.0	65.5
17	14.7	29.0	19.0	49.0
18	5.8	13 0	9.0	4.0
19	13.9	39.0	22.0	76.5
Total :	186.5	411.5	246.5	459.8
Mean :	9.82	21.66	12.97	24.20

The loppings were removed from all the trees. The dressed trees (19 trees shown in Table) weighed 349.5 Kg. The loppings as such for 19 trees weighed 450.8—349.5 = 110.3 Kg. The mean weight of loppings per tree is 5.8 Kg. The loppings and side branches will constitute 24.0% of total wet weight of trees. The dryage of loppings will be 50%. These loppings constitute a source of fuel and is in demand for household use.

The mean yield per tree at the age of 5, under rainfed condition in sandy soil, works out to 18.40 Kg. (freshly cut moist). The dryage will be 30%. In that case the dry weight (estimated) will be 12.95 or 12.88 Kg/tree over 5 years period. The growth is usually more during the third year.

The below ground portion of the casuarina tree is constituted of lateral and main roots and it will be in the proportions of 3-5% or 60 to 100 Kg of roots portion for every 2 tonnes yield of trees. The dryage is as in the trunk portion and this portion is also utilized as fuel

Ref: 15, 16, 17, Gave the cultural practices, the cost of cultivation of casuarina at Madurantakam.

Ref: 18 Described the cultural practices, the cost & energy inputs, the yield of casuarina as practiced at Injambakkam.

Ref: 28 Administration Report of the Tamilnadu Forest Department, for the year 1971-72. Government of Tamilnadu—1976, details the casuarina Research Programmes underway at different Research Centres.

Ref: 29 "The Nitrogen Cycle", C. L. Delwiche, p. 229-238. "Readings from Scientific American", "Ecology, Evolution and Population Biology", Publisher: W. H. Freeman & Co, 660, Market Street, San Francisco, CA 94104.

Ref: 21 Describes the importance of micronutrient elements for 'N' fixing bacteria.

Ref: 20 Gives the figure of land utilization in Tamilnadu, providing a sound base for "Energy Plantations" in the state.

Ref: 30 A. Sekhar Anandam, B.Sc. (Ag.), gave information on *Casuarina jungheeniana*. Year of maturity for *C. jungheeniana* is not fixed so far. Anyhow the age of maturity is likely to be the age fixed in the case of *Casuarina equisetifolia.*

Similarity and field characters with *Casuarina equisetifolia.*

Serial No.	C. Jungheeniana	C. equisetifolia
1.	Sexes - available only male plants flowering but not fruiting.	Available male and female plants.
2.	Propagated by means of air layering.	Seed origin.
3.	Side branches are in habit of regular shedding.	Regular shedding.
4.	Root suckers well.	Nil.
5.	Watering (in initial stage) is not necessary.	Watering is necessary for one year.
6.	Strong drought resistant.	Poor resistant.
7.	Shallow rooted.	Shallow rooted.
8.	Height and diameter growths are more or less equal to *C. equisetifolia*.	Equal
9.	Needles are strong and longer than *C. equisetifolia.*	Needles are thin and shorter.
10.	The branches are drooping down.	The branches are stretching side wards.
11.	The colour of the needles is brown	The colour of the needles is green
12.	Graceful looking like coniferous trees.	—
13.	Splitting - good.	Good.
14.	Dead wood are immediately affected by insects.	Gradually.
15.	No smoke while burning.	No smoke while burning.
16.	Needles are good burning materials compared to *C. equisetifolia.*	Fair burning materials.
17.	Serve as good wind belt.	—

60—65% of success in air layering in *C. jungheeniana.*

Ratooning i.e. Coppicing - promising and performing well in *C. Jungheeniana.*

No 'N' fixing nodules are found in *C. jungheeniana.*

SECTION. 4: COST AND ENERGY ANALYSIS

This section deals with the agricultural Cost and Energy analysis of the Plantations to grow the fuel for the power plant. It is believed that using values derived from current agricultural practices in different locations in Tamil Nadu and Pondichery, we have arrived at a conservative estimate of the Costs and Energies involved in such Plantations. There are 4 sub-sections as follows:

(1) Basis of calculation.

(2) Explanation of area-calculations for daily harvest.

(3) Explanation of Capital and Operating Costs and Operating Energy values.

(4) Method of calculating returns.

Sub-Section: 1. Basis of Calculation: The basis of the study is that the electrical power is generated in a plant of installed capacity of 160 MW with a annual load factor of 62.5% i.e. average power production of 100 MW. Four 100 MW plants are now in operation in India and this seems to be a median size for thermal plants. It is assumed that (a) coal-fired and wood-fired plants are approximately of the same cost and facility of operation and (b) that the operation of the plant and Plantations are essentially independent. A complete sensitivity analysis will reveal the real optimum in power plants run on wood, and the nature of the interactions if they exist, in the operation of the plant and Plantations. Such analysis has not been carried out. Neither does this study deal with the nature of the body or bodies to run the Plantations; in the present political climate, it is likely to be a public sector organisation.

The plant will be situated at the centre of a circle of radius 50 km containing the forests. All the land necessary cannot be bought or leased at one point, so the 50-km-radius circle contains the necessary few hundred square kilometres of forest for the plant. It is also not desirable to have too many large stands in close proximity because of the fire hazard.

Although the main basis is a 100 MW power generation values are not reported on this basis in the detailed calculations; for *e.g.* a cost for ploughing, will not be stated as ploughing: Rs. $x/100$ MW. Because of the agricultural operations and the variations therein, it has been found that a per-hectare basis is more convenient for the calculations. The connections between the power generation capacity and the area basis have been established using the following steps :

(1) determine the yield of fuel-wood in a particular area (which uses a particular set of cultural operations) after say, *n* years, which is known as the cycle-time.

(2) knowing the calorific value, efficiencies, and other parameters, obtain the number of hectares harvested per day needed to continuously fuel the power plant.

(3) reduce the operations carried out over the total area over the total cycle-time, to a per-hectare cycle-time requirement; ie. the labour and material per hectare for a cycle-time.

(4) using standard values of Labour and Material Costs and Energy requirements, obtain the Cost and/or Energy for each operation on a per-hectare cycle-time basis.

(5) knowing these values, multiply them by the total number of cycle-time hectares to obtain the total cost of fuel for 100 MW.

It is worth restating here that the per-hectare basis is convenient for the calculations shown here. Other studies have not used this basis because they do not seem to have taken into account, land recycling in continuous feeding of power plants. (See Bibliography of Sections 1, 2). However it is not known whether the presently chosen basis is scale-independent, though efforts have been made to make it so, using discussions with large-scale farmers of casuarina. It is shown in the last section that if the calculation procedure is scale-dependent, then the costs arrived at, are conservative and therefore will present the study in a more favourable light.

TABLE I

Locations and Cultural Practices of Casuarina Plantations

S.No.	PLACE	Year	IRRIGATION	Fertilizers	Spacing & Population	Years to Harvest	Yield In tonnes/ha-yr	Reference	REMARKS
1	Pondicherry	1978	Initial watering for 30 days - 4 women/ha-day. Subsequent watering once a fortnight during the 4 summer months for 3 years.	None	1 M x 1 M 10 000 plants/ha	4	62.5	Personal communications (Ref: 14)	Mortality about 20%; well irrigated plants; yield of 250 tonnes/ha - 4 years at 30% moisture This comprises of logs weighing 200 tonnes/ha - 4 years at 30% moisture, 28% of logs as loppings i.e. 56 tonnes/ha - 4 years at 50% moisture and 5% of logs as roots i.e. 10 tons/ha - 4 years - at 30% moisture.
2	Madurantakam	1977	Initial watering as above; subsequent watering once a fortnight during the 4 summer months for 4 years.	60 kg. Urea, 60 kg. MOP and 125 kg. Super-Phosphate/ha (or) 245 /kg of N : P : K ::: 17 : 17 : 17 complex-fertilizer/ha	1 M x 1 M 10000 plants/ha	5	25	Personal contact (Ref: 15)	Yield of 125 tonnes/ha - 5 years at 30% moisture - comprising 100 tonnes logs at 30 % moisture, 28% of logs as loppings i.e. 28 tonnes at 50% moisture and 5% of logs as roots, 5 tonnes at 30% moisture.
3	Injambakkam	1977	Initial watering for 25 days-25 woman days/ha. Subsequent watering for 9 months in the first year-135 woman days/ha	None	2 M x 2 M 2500 plants/ha	5	13	Personal contact (Ref: 18)	Yield of 65 tonnes/ha 5 years at 30% moisture; comprising 50 tonnes logs at 30% moisture; 32% of logs as loppings i.e. 16 tonnes at 45% moisture and 5% of logs as roots, 2.5 tonnes at 30% moisture, on sandy soils in the coastal belt.
4	Forest Department	1977	Initial watering for 30 days–20 woman-days/ha. Subsequent watering for 6 months in the first year—16 woman days/ha	None	2.5 M x 2.5 M 1600 plants/ha	7	9.28	Communications from Forest Department (Ref: 25)	Yield of 65 tonnes/ha - 7 years at 20% moisture. This includes 50 tonnes logs/ha - 7 years at 20% moisture; 33.5% of logs as loppings i.e. 16.75 tonnes at 40% moisture; 5% of logs as roots i.e 2.5 tonnes/7 years at 20% moisture.
5	Thana	1977	Watering for a year	Urea Cowdung	1.83 M x 1.83 M 3000 plants/ha	4	71.25	Personal contact (Ref: 27)	Yield of 285 tonnes/ha - 4 years; annual average rainfall of about 250 cm.

Sub-section. 2: Explanation of area-calculations for daily harvest:

Table I presents in a summarised form the cultural practices, yields and regions chosen for analysis from Tamil Nadu and Pondicherry. Thana District values have not been used further, though the values are presented in the table. Knowing the yields from Table I and following the procedure given above, the areas required for the daily cultivation and harvest to feed the power plant continuously are given in Table II. These calculations are explained before this table.

Assumptions and Justifications :

(1) Basis 100 MWe (as explained already).

(2) 30% overall efficiency of the plants; it is assumed that a decentralized generation and distribution system can work at approximately 5% more efficiency than existing systems, e.g. Ennore which operate at 25% efficiency.

(3) the fuel wood has a calorific value of 4950 kcal/kg.

Refer: Forest Bulletin No. 79 of F.R.I. Dehra Dun (1932). This reference gives the calorific value at 6.22% moisture. In this study a 30% wet wood has been allowed if the harvest is after 4 or 5 years and the calorific value is obtained by linear interpolation. This gives a value of 3726 kcal/kg. For seven year old trees, moisture content is 20% and the calorific value allowed is 4258 kcal/kg. These moisture values are from Table I and reference 14 of section 2.

(4) to obtain the total area for growth, the procedure is to take the total number of MWH/year, divide by 0.30 for the efficiency. This energy is then divided by the calorific value of the wood that can be harvested per year per hectare.

Sample calculation:

Pondicherry yield = 250 tonnes/ha – 4 years, where 4 years is a 'cycle-time'.

Total energy needed per year :

$$\underbrace{100 \times 10^6\ (J/s) \times 3600\ (s/hr) \times 24\ (hrs/day)}_{\text{Energy/day}} \times \underbrace{100/30}_{\text{Efficiency.}} \times \underbrace{0.94/4950}_{\text{Cal. value of bone dry wood/kg.}} \times \underbrace{1/(4.187 \times 10^6)}_{\text{Conv. factor}}$$

= 1305.5 tonnes/day of bone dry wood.

$\therefore$ area needed to cultivate requirements by Pondicherry standards

= 1305.5 x 365 (t/yr) x 4 (yrs./cycle-time)/250 (t/ha-cycle-time) x 1/0.74 (dryness factor) = 10 892 ha.

(5) The total area of the plantation has 2.5% road surface and includes 250 ha for infrastructural facilities, *i.e.*

$A_T = (A_0 + 0.025\, A_0 + 250)$ ha, where A_0 is the actual area required and A_T is the total area.

(6) A cycle-time of say 4, 5 or 7 years is necessary to harvest the crop of a particular block. The find the "cycle-block" – *i.e.* the block of land which has to be harvested every cycle-time to give the fuel needed, we proceed as follows :

One cycle-block is to be processed every day, but a particular cycle-block will be harvested once every cycle-time. The question is how many days will the plantation be processed a year to give the desired energy.

Assume 27J working days a year. Harvesting and all other operations take place on this number of days a year, each day one (different) cycle-block being processed. The other days are to allow for inclement weather, monsoon, leave other than weekly-off, etc. However in these 275 days enough is harvested to keep the power-plant going for 365 days.

Sample calculation :

Cycle-time total area = 10 892 hectares

$\therefore$ Cycle-block = (10 892 ha)/4 (yrs/cycle-time) x 275 (days/year) = 9.9 cycle-time ha/day.

To reconfirm that a cycle-block will be sufficient to power the plant if one cycle-block is processed on one day :

Bone dry wood/day = 1305 tonnes.

Yield per cycle-block = 250 tonnes/ha-cycle-time.

Cycle-block = 9.9 ha cycle-time/days.

$\therefore$ bone dry wood/cycle block = 9.9 x 250 x 0.7 = 1732 tonnes/day.

Excess/day over requirement : 1732—1305 = 427 tonnes/day.

This much has to do for the remaining 90 days.

$$i.e. \quad 427 \times 275/90 = 1305 \text{ tonnes/day} \equiv \text{demand}$$

TABLE II : **Size of Cycle-Block for daily harvesting**

Place	Yield (tonnes/ha–cycle-time)	% moisture	A_0 (ha)	A_T (ha)	Cycle-Block cycle-time ha/day
Pondicherry	250/ha - 4 years	30	10 892	11 414	9.9
Madurantakam	125/ha - 5 years	30	27 229	28 160	19.8
Injambakkam	65/ha - 5 years	30	52 363	53 923	39.04
Forest Department	65/ha - 7 years	20	64 145	65 999	33.32

Sub-Section 3 : Explanation of Capital and operating costs and operating energy values.

This sub-section presents the capital and operating cost analysis of the four cultural practices in Pondicherry, Madurantakam, Injambakkam and Forest Department. The presentation is in tabular form with explanatory notes. Two points need to be emphasised here: (1) the capital costing presupposes a method of calculating the returns; however the returns are highly dependent on the nature of the corporation that is going to run the plant and plantation, and also on the investment policies. These are discussed in the next sub-section. Here a final presentation is made for a particular choice of investment decisions. (2) though the cultural operations have been studied and followed in the analysis, some modifications have been made to bring them into the modern context. Thus the Forest

Department does not use tractors, hence here no tractors are allowed for. However, security staff and managerial staff have been provided. Also the labour employed is guaranteed a wage throughout the year even though currently they are employed by the Forest Department on a strictly casual basis. To anticipate a result of this study the Forest Department cultural practice will always make a loss in this Energy Plantation even though they are currently a profit making organisation. The continuance of archaic practices are energy efficient but exploitative of the human condition. The optimality criteria, energy efficiency and employment satisfaction are therefore important in future development studies.

Table III gives the Capital Cost analysis. There is no analysis of Capital Energy requirement.

Table III is based on the following investment decisions :

(a) all land is bought, not leased or available free of cost.

(b) all the roads have to be laid from scratch.

(c) all other equipment is bought. *e.g.* tractors, lorries, pumps, etc.

Other investment decisions are also discussed in the sub-section on calculating returns. These results are analysed in the last section.

Tables IV, V, VI & VII give the operating energy requirements for the 4 different cultural practices. The calculations were made on a per-hectare, per cycle-time basis after reducing the data obtained from the various regions to this basis. These data were obtained from the large-scale casuarina plantations of the Injambakkam (100 ha), Madurantakam. Polambakkam and Sirunallur regions (about 2000 - 3000 hectares) of Tamil Nadu. These references are to be found in Section 2. An attempt has been made to make the values both conservative and scale-independent ; if economics of scale are indeed present, then they will be in favour of the present study since the area dealt with here are much larger than the areas studied. Each table has 23 headings for which the explanations are given before the set of tables. Table VIII is a comparative statement of all the areas.

LIST OF HEADINGS FOR TABLES IV TO VIII

Note : Not all of these operations are used in all areas.

1. (a) or 1 (b). Animal or Tractor ploughing as applicable.
2. Harrowing.
3. Cultivating.
4. Trimming.
5. Nursery raising.
6. Marking and pitting.
7. Planting.
8. Initial watering for 30 days.
9. Subsequent watering during 16 weeks of summer, once a fortnight for 3 years.
10. Digging and hoeing for weeding.
11. Ploughing and weeding.
12. Fertilizer application.
13. Pruning after 2 years.
14. Felling, cutting, stacking and loading.
15. Transporting.
16. Lorry drivers, cleaners, mechanics.
17. Security staff.
18. Supervisory staff.
19. Managerial staff.
20. (a), (b): Earning at the rate of Rs. 200/tonne sold and Rs. 100/tonne sold.
21. (a) Labour operating cost without costs due to a weekly leave allowance/ha cycle-time.

    (b) Material operating cost/ha cycle-time.
22. Total operating cost including those due to leave allowance at 7/6 of labour operating cost plus materials cost.
23. Output/Input ratio for energy not including solar energy for photosynthesis. These are dimensionless numbers.

TABLE IV

Pondicherry: 9.9 ha/day; 1m x 1m; Base: hectare cycle-time.

Item	No. of Units	Units	Cost Rate Rs.	Cost Total Rs.	%	Energy Rate '000 k cal	Energy Total '000 k cal	%
1 b	5	lit. diesel	2	10	—	10.5	52.5	—
	0.31	man-day	7	2.2	—	2	0.6	—
5	10 000	seedling	0.006	60	—	0.152	1520	17.03
6	20	man-day	7	140	1.68	2	40	—
7	25	woman-day	4	100	1.10	2	50	—
8	120	woman-day	4	480	5.79	2	240	2.68
9	96	woman-day	4	384	4.63	2	192	2.15
10	15	man-day	7	135	1 62	2	30	—
11	2	man-day	7	14	—	2	4	—
12	4	animal-day	5	20	—	24	96	1.07
13	10	man-day	7	70	—	2	20	—
14	400	man-day	7	2800	33.77	2	800	8.96
15	500	lit. Diesel	2	1000	12.06	10.5	5250	58.83
16	57	man-day	12	684	8.10	2	114	1.05
17	219	man-day	7	1533	18.49	2	438	4.91
18	19	man-day	12	228	2.75	2	38	—
19	31	man-day	25	775	9.05	2	62	—
20 a.	250 000 kg	—	0.2	50,000	—	3.7	925 000	—
b.	250 000 kg	—	0.1	25 000	—	3.7	925 000	—
21 a.	—	—	—	7425	—	—	3623	—
b.	—	—	—	1010	—	—	5303	—
22	—	—	—	9673	—	—	9530	—
23	—	—	—	—	—	—	97.1	—

TABLE. V

Madurantakam: 19.8 ha/day; 1 m x 1 m; Base: hectare cycle-time.

Item	No. of Units	Units	Cost Rate Rs.	Cost Total Rs.	%	Energy Rate '000 k cal	Energy Total '000 k cal	%
1 b	5	lit. diesel	2	10	—	10 5	52.5	—
	0.31	man-day	5	1.6	—	2	0.6	—
2	2.5	lit. diesel	2	5	—	10.5	26.3	—
	0.15	man-day	5	0.8	—	2	0.3	—
3	2.5	lit. diesel	2	5	—	10.5	26.3	—
	0.15	man-day	5	0.8	—	2	0.3	—
4	5	man-day	5	25	—	2	10	—
5	10 000	seedlings	0.006	60	—	0.152	1520	13.50
6	20	man-day	5	100	1.49	2	40	—
7	25	woman-day	3	75	1.12	2	50	—
8	120	woman-day	3	360	5.39	2	240	2.13
9	128	woman-day	3	384	5.75	2	256	2.27
10	15	man-day	5	75	1.12	2	30	—
11	4	man-day	5	20	—	2	8	—
	8	animal-day	5	40	—	24	192	1.70
12	245	kg. fertilizer	—	325	4.86	18.75	4594	40.78
13	10	man-day	5	50	—	2	20	—
14	400	man-day	5	2000	29.94	2	800	7.10
15	250	lit. diesel	2	500	7.49	10.5	2625	23.30
16	28	man-day	12	336	4.31	2	56	—
17	329	man-day	5	1645	24.63	2	658	5.84
18	10	man-day	12	120	1.79	2	20	—
19	24	man-day	25	600	8.98	2	48	—
20 a	125 000	kg	0.2	25 000	—	3.7	462 500	—
b	125 000	kg	0.1	12 500	—	3.7	462 500	—
21 a	—	—	—	5893	—	—	3949	—
b	—	—	—	835	—	—	7324	—
22	—	—	—	7710	—	—	11 931	—
23	—	—	—	—	—	—	38.8	—

TABLE VI

Injambakkam : 39.04 ha/day ; 2m x 2m ; Base : hectare cycle-time.

Item	No. of Units	Units	Cost Rate Rs.	Cost Total Rs.	Cost %	Energy Rate '000 k cal	Energy Total '000 k cal	Energy %
1 a	2	man-day	7	14	—	2	4	—
	4	animal-day	5	20	—	24	96	2.20
5	5000	seedling	0.006	30	—	0.152	760	17.40
6	6	man-day	7	42	—	2	12	—
7	3	Woman-day	4	12	—	2	6	—
8	25	Woman-day	4	100	1.55	2	50	1.15
9	506	Woman–day	4	2024	31.26	2	1012	23.17
11	2	man-day	7	14	—	2	4	—
	4	animal-day	5	20	—	24	96	2.20
13	3	man-day	7	21	—	2	6	—
14	100	man-day	7	700	10.81	2	200	4.58
15	130	lit. Diesel	2	260	4.02	10.5	1365	31.25
16	14	man-day	12	168	2.22	2	28	—
17	329	man-day	7	2303	35 57	2	658	15 06
18	13.5	man-day	12	162	2.50	2	27	—
19	24	man-day	25	600	9.27	2	48	1.10
20 a	65 000	kg	0.2	13 000	--	3.7	240 500	—
b	65 000	kg	0.1	6500	—	3.7	240 500	—
21 a	—	—	—	6225	—	—	2987	—
b	—	—	—	260	—	—	1365	—
22	—	—	—	7523	—	—	4850	—
23	—	—	—	—	—	—	49.6	—

TABLE VII

Forest Department : 33.32 ha/day ; 2.5m x 2.5m ; Base : hectare cycle-time.

Item	No. of Units	Units	Cost Rate Rs.	Cost Total Rs	Cost %	Energy Rate '000 kcal	Energy Total '000 kcal	Energy %
1 a	2	man-day	7	14	—	2	4	—
	4	animal-day	5	20	—	24	96	3.34
5	1600	seedling	0.006	9.6	—	152	243	8.46
6	5	man-day	7	35	—	2	10	—
7	4	woman-day	4	16	—	2	8	—
8	20	woman-day	4	80	1.73	2	40	1.39
9	16	woman-day	4	64	1.38	2	32	1.11
10	4	man-day	7	28	—	2	8	—
13	3	man-day	7	21	—	2	6	—
14	80	man-day	7	560	12.11	2	160	5.57
15	130	lit. Diesel	2	260	5.62	10.5	1365	47.49
16	12	man-day	7	84	1.82	2	24	—
17	411	man-day	7	2877	62.20	2	822	28.60
18	11	man-day	12	132	2.85	2	22	—
19	17	man-day	25	425	9.19	2	34	1.19
20 a.	65 000	kg	0.2	13 000	—	4.02	273 000	—
b.	65 000	kg	0.1	6500	—	4.02	273 000	—
21 a.	—	—	—	4366	—	—	1489	—
b	—	—	—	260	—	—	1365	—
22	—	—	—	5354	—	—	3102	—
23	—	—	—	—	—	—	88.0	—

TABLE VIII

Item	Pondicherry				Madurantakam				Injambakkam				Forest Dept.			
	Cost Rs.	%	Energy '000 k cal	%	Cost Rs.	%	Energy '000 k cal	%	Cost Rs.	%	Energy '000 k cal	%	Cost Rs.	%	Energy '000 k cal	%
1a	—	—	—	—	—	—	—	—	36	—	101	2.09	36	—	101	3.26
b	12.60	—	53	—	12	—	53	—	—	—	—	—	—	—	—	—
2	—	—	—	—	6	—	27	—	—	—	—	—	—	—	—	—
3	—	—	—	—	6	—	27	—	—	—	—	—	—	—	—	—
4	—	—	—	—	29	—	12	—	—	—	—	—	—	—	—	—
5	70	—	1773	18.60	70	—	1773	14.90	35	—	887	18.32	12	—	284	9.16
6	163	1.69	47	—	117	1.52	47	—	49	—	14	—	41	—	12	—
7	117	1.21	58	—	88	1.14	58	—	14	—	7	—	19	—	9	—
8	560	5.79	280	2.94	420	5.44	280	2.35	117	1.55	58	1.20	93	1.74	47	1.52
9	448	4.63	224	2.35	448	5.81	299	2.51	2361	31.35	1181	24.39	75	1.40	37	1.19
10	158	1.63	35	—	88	1.14	35	—	—	—	—	—	33	—	9	—
11	40	—	117	1.2	63	—	201	1.69	36	—	101	2.09	—	—	—	—
12	—	—	—	—	325	4.21	4594	38.61	—	—	—	—	—	—	—	—
13	82	—	23	—	58	—	23	—	25	—	7	—	25	—	7	—
14	3267	33.78	933	9.80	2333	30.24	933	7.84	817	10.85	233	4.81	653	12.20	187	6.03
15	1000	10.34	5250	55.00	500	6.48	2625	22.06	260	3.45	1365	28.19	260	4.86	1355	43.70
16	798	8.25	121	1 27	392	5.08	65	—	196	2.60	33	—	98	1.83	28	—
17	1789	18.50	511	5.36	1919	24.88	768	6.45	2687	35.68	768	15.86	3357	62.72	959	30.93
18	266	2.75	44	—	140	1.81	23	—	189	2.51	33	—	154	2.88	26	—
19	904	9.35	72	—	700	9.07	56	—	700	9.29	56	1.16	496	9.27	40	1 29
20a	50 000	—	925 000	—	25 000	—	462 500	—	13 000	—	240 500	—	13 000	—	273 000	—
b	25 000	—	925 000	—	125 000	—	462 500	—	6500	—	240 500	—	6500	—	273 000	—
22	9673	—	9530	—	7710	—	11 931	—	7523	—	4850	—	5354	—	3102	—
23	—	—	97.1	—	—	—	38.8	—	—	—	49.6	—	—	—	88.0	—

List of headings:

1(a) or (b): Animal or tractor ploughing as applicable. The capital and animal shed costs have already been shown in the capital cost budget. Here only a maintenance and feed allowance is charged at Rs. 5/- day. The labour is charged as so much per man day as shown in the tables. The energy cost is taken as 2000 kcal/man day or 2000 kcal/women day and a bullock is energetically valued at 24 000 kcal/bullock day. These figure s are from A. Makhijani, "Energy and Agriculture in the Third World" (Bollinger Press, Cambridge, Mass, 1976), p. 140. The energy allowed here is for total sustenance, including metabolic energy, not just energy available for work.

One tractor ploughs a hectare in 2.5 hours. Diesel costs Rs. 2/litre. Diesel consumption is at the rate of 2 litres/hour. Thus 1 hectare can be ploughed at a usage rate of 5 litres diesel costing Rs. 10. The energy per litre of diesel consumed is 10 500 kcal (from any Handbook, e.g. Perry's Handbook). Ploughing labour for 2.5 tractor hours is prorated from the daily rate of Rs. 7/man day. This is once per cycle-time.

2. Harrowing: Harrows driven by tractors needing 1.25 hrs/ha. The unit diesel cost and unit diesel energy are as shown in the tables.

3. Cultivating: Cultivators driven by tractors needing 1.25 hrs/ha.

4. Trimming and plastering of bunds: for moisture conservation and prevention of soil erosion. Only Madurantakam region practices this. This is done by manual labour and requires 5 man days per hectare per cycle-time.

5. Nursery raising: The young seedlings are transplanted after two nursery stages. Current practice is that seeds are raised in small beds; planted into beds with larger spacing and finally transplanted to the field. The amount of manure for each bed, labour required and watering has been accounted for. The energy and cost values are as obtained from an averaging of the operations required to raise the nursery.

The next 9 headings are explained in the tables. Their cost and energy values are as per current practice. Lighter manual labour is carried out by women who are paid less per day. Each item is on a per hectare per cycle-time basis.

6. Marking and Pitting.

7. Planting.

8. Initial watering for 30 days.

9. Subsequent watering during 16 weeks of summer, once a fortnight for 3 years.

10. Digging and hoeing for weeding.

11. Ploughing and weeding.

12. Fertilizer application is done only in Madurantakam; see Section 3 ; 245 kg. of fertilizer N : P : K : : : 17 : 17 : 17 : added per hectare cycle-time at Rs. 325. Energy is 18 750 kcal/kg of fertilizer, from A. Makhijani, p.141.

13. Pruning after 2 years; no credit taken for loppings at this stage as pruning is necessary for healthy growth.

14. Felling: Of the number of labour employed, 1/4 are used for actual axeing, 1/2 are used for trimming and sawing and 1/4 are used for stacking, transport and loading on lorries. Actually, all equipment and labour for this operation is only needed 4 years after starting the plantation. Here we have charged these items from the begining itself and thus are paying more than need be the case in practice.

15. Transporting: The power plant is assumed to be at 50 km. average distance from the plantation block. The lorries give 5 km/litre diesel; total turn-around time is 4 hours including 2 hours for the round trip plus 2 hours for loading-un loading, hence six trips a day carry about 2500 tonnes/day of fresh (moist) wood from a cycle-block. The Forest Department wood being dryer, less is handled per cycle-block.

16. Lorry drivers, cleaners and mechanics: 1 driver per lorry, two cleaners, and 3 mechanics per 2 lorries in operation per shift. The numbers in headings 15 and 16 have been reduced to a per hectare per cycle-time basis starting from a cycle-block basis.

17. Security Staff: Needed only for 2 year and older plants. At the rate of 1 man/10 ha for each of 3 shifts. Only land, on which work is not carried out is watched, i.e. if harvesting is going on in a block no watch and ward staff are allowed for.

18. Supervisory Staff: 1 per 50 labourers.

19. Managerial Staff: Calculated as 10% of all other costs.

20. (a) and (b) earnings at the rate of Rs. 200/tonne sold and Rs. 100/tonne sold.

21. (a) is the labour operating cost *without* weekly leave allowances/ha cycle-time.

(b) is the material operating cost/ha cycle-time.

22. is the total operating cost including leave allowances and material costs per ha-cycle-time. Leave allowances at 7/6 of all labour operating cost, to account for weekly-off. Each 6 man crew will have a 7th as standby.

23. Out put/In put ratio for energy not including solar energy for photosynthesis.

In Table VIII a comparison of all four areas is given. In this, leave allowances have been given in the Table itself.

Sub-Section: 4. Method of Calculating Returns:—

Tables III to VIII give the calculations of capital and operating costs based on certain investment decisions. As pointed out before a method of calculating returns is presupposed in calculating even the capital costs. Thus this sub-section and the previous one are connected by feedback loops.

Several alternate investment decisions were considered and the various costs and returns estimated. These possibilities are listed below. One other factor that dictates the choice of decision and its feasibility is the selling price of fuel-wood. The current selling price is taken as Rs. 200/tonne, ex-plantation. However since the Energy Plantation concept is an alternative to coal burning, another selling price has been used. This is to take the equivalent energy value to coal and to peg the price of wood to a coal-equivalent.

The Tamil Nadu Electricity Board buys coal at Rs. 136/tonne delivered at site. The calorific value is 4800 kcal/kg. (These values are by courtesy of TNEB). Therefore the price of fuel-wood should be : 136 Rs./tonne x 3700/4800 = Rs. 105 tonne – taken as Rs. 100/tonne. This means that the energy plantation supplies fuel-wood to the power plant such it can directly replace calorie for calorie, wood for coal, at a price of Rs. 105/tonne for 30% wet wood. The pegged price of Forest Department wood is Rs. 119/tonne, since its moisture content is less.

The important variables in calculating returns are as follows:

(1) selling price of wood.

(2) interest rates on borrowings.

(3) whether land is charged or not.

(4) whether all the land is bought in one lot or as cultivation proceeds; the latter case also implies that the roads are laid as cultivation proceeds.

(5) whether there is a credit taken for intercropping harvests, loppings, ratooning, and other by-products.

(1) The selling price of wood has been explained already.

(2) Interest rates on borrowings : Calculations have been carried out for 5% and 9% rates. If government schemes are supported by government debentures, a rate of 3-5% is allowed as interest. Thus the calculations have been carried out at a rate of 5% interest. Also deferred payment schemes are allowed to farmers by

nationalised banks. Such schemes allow a holiday period for repayment, of 4-8 years and interest charged on the principal is allowed at simple interest. Since this scheme employs a large number of labourers, about 10 000 in number in most cases, it was felt that such deferred payment schemes could be made available to an energy plantation. The 9% rate is available from nationalised banks on agricultural borrowings or through Agricultural Refinance Corporations. In both 5% and 9% rates, interests have been compounded and not taken at simple interest.

(3) If the land is completely bought (an unlikely contingency in the present socio-political situation) then a certain pay-back period is obtained as a result of the calculations. On the other hand if the land is made available free of cost to a public sector corporation, a different set of calculation ensues. Both sets are presented.

(4) A decision has to be made in presenting the returns, whether all the land is bought in one lot and all the roads, infrastructure etc. provided right away or whether the land is to be bought piecemeal as plantation progresses. Both sets of returns are presented. In buying land piecemeal, it has been decided that land is bought once a year for four years, five years or seven years as the case may be.

(5) Intercropping with groundnut, sorghum etc. is possible for 2 years. Also ratooning yields quite a bit after the first harvest. No credit is taken for any such by-products. Also no credit is allowed for wood ash which is a good fertilizer.

Based on these various possibilities, 64 separate returns calculations have been carried out and are presented on a 4 x 16 matrix in Table IX. Each row represents a different cultural operation. Each column has a set of numbers representing the pay-back period in years. The column headings represent the method of calculating the pay-back period with the selling price and interest rates on borrowings given in the columns.

The calculation of the pay-back period is explained with the help of the following sample calculation.

Sample Calculation: Reference Item (11) in Table IX.

Basis: Pondicherry yield: 250 tonnes/ha cycle-time.

Price of wood : Rs. 100/tonne

Interest rates on borrowings: 5%/ annum.

Land is bought in instalments, once every year, for four years.

Roads are laid once a year, for four years.

Notes:
1. The plantation does not have any sales for the first four years.
2. Interest is compounded on capital and operating costs.
3. Depreciation is taken as straight-line depreciation at 3% for buildings, 10% for machinery, 20% for tools and implements and 20% for animals. As can be seen from Tables III to VIII, the percentage contribution of these items is so low that no further refinements were made in depreciation calculations.
4. No other development reserve is kept aside. The payback period is the time in years needed to pay-off all capital costs and borrowings. At the end of that period the land is completely owned by the plantation corporation.
5. All values are reported in thousands of rupees. (Rupees x 10^{-3}).

1st Year:

(a)	Capital other than land and roads+interest.	(Table III)	16 300
(b)	25% of land and roads+interest	(Table III)	51 405
(c)	Operating cost+interest	(Table IV)	34 961
(d)	Depreciation on buildings, machinery, implements etc.		875
			103 541

		2nd Year :	*3rd Year :*
(e)	Total with interest (from previous year)	108 718	205 757
(b)		51 405	51 405
(c)		34 961	34 961
(d)		875	875
		195 959	292 998

		4th Year :
(e)		307 648
(b)	......(All land bought)	51 405
(c)		34 961
(d)		875
		394 889

		5th Year :	*6th Year :*
(e)		414 633	401 526
(c)		34 961	34 961
(d)		875	875
		450 469	437 362
(f)	Returns on sales (to be subtracted)	68 063	68 063
		382 406	369 299......

	.......24th Year :
(e)	14 367
(c)	34 961
(d)	875
	50 203
(f)	68 063
	–17 860

i.e. at the end of the 24th year, there is a nett profit. Therefore 24 years is considered the pay-back period. If for this same set of investment decisions, a 10% annual reserve is held back from the returns, the pay-back period is lengthened to 36 years. *This is entered in parenthesis in the same column.* So the scheme is still profitable for this condition. The entries marked NP imply non-profitability; that is, the capital or/and operating costs with interests always accumulate more than the returns on fuel-wood.

TABLE IX

PAY BACK PERIODS IN YEARS

Place	At sale price Rs. 200/- per tonne 5% Interest/annum				At sale price Rs. 200/- per tonne 9% Interest/annum				At sale price Rs. 100/- per tonne 5% Interest/annum				At sale price Rs. 100/- per tonne 9% Interest/annum			
	Only Road laid in Instalments	Only Road laid Initially	Land bought & Road laid in Instalments	Land bought & Road laid Initially	Only Road laid in Instalments	Only Road laid Initially	Land bought & Road laid in Instalments	Land bought & Road laid Initially	Only Road laid in Instalments	Only Road laid Initially	Land bought & Road laid in Instalments	Land bought & Road laid Initially	Only Road laid in Instalments	Only Road laid Initially	Land bought & Road laid in Instalments	Land bought & Road laid Initially
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
1. Pondicherry	6	7	9	9	7	7	9	9	15	16	24 (36)	25	27	30	NP	NP
2. Madurantakam	15	16	23	25	23	27	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
3. Injambakkam	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
4. Forest Department	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP

SECTION. 5: DISCUSSIONS AND CONCLUSIONS

This section analyses the tables and lists some of the conclusions. It has seven sub-sections as follows :

(a) Sources of error,

(b) Why the estimates are considered conservative,

(c) Analysis of the capital cost-table,

(d) Analysis of the operating cost-tables,

(e) Analysis of returns-table,

(f) Cost conclusions and

(g) General conclusions.

To restate the perspective of the study might be useful. An attempt has been made to study the cultural practices in four areas in some detail, with a view to find out if Energy Plantations are feasible. The data were obtained from reliable sources, especially from agencies like the Farm Science Centre, Pondicherry, (Krishi Vigyan Kendra, ICAR scheme). Also Forest Department sources were relied upon for yields. The cost values and energy values are our own responsibility. However, whenever possible, quotations were obtained from commercial sources. The study is still a preliminary study and a detailed systems study is necessary to make final decisions.

(a) Sources of error :

The investment decisions have been made with certain limitations in view. It is not known whether such large tracts of land can be purchased or whether they will be set aside for energy forests. No allowance has been made for land revenue or property taxes. No allowance has been given for agricultural income-tax since the material is for captive use. No fire insurance is provided for. No bonus or extra allowances are given for worker's welfare. No calculations have been made for colonies or housing.

No allowance has been made for inflationary tendencies.

It is felt that errors in yield of material are small because only average yields from those reported have been considered. For instance, the maximum yield in Pondicherry has been reported to be 300 tonnes/ha-4 years of total combustibles. A genuine source of error could be the calorific value of fuel wood used. Newer data needs to be obtained on this vital factor.

As stated subsequently, the maximum capital allocations are for land and roads. Hence errors in all other items are ignorable because they form a small percentage of total cost. In the operating budgets, the errors are, once again, critical in only a few items which contribute a major percentage of the costs, especially felling etc. It is felt that the errors, if at all, are on the conservative side.

(b) Why the estimates are considered conservative :

It may be noticed that land and roads form more than 80% of the capital costs (See also Alich and Inman, Ref. 4, Section. 1). Most marginal land is not valued at Rs. 10 000/ha today. The road area, 2.5%, is more than most forests have today. Storage tanks have been provided, though rain water storage is usual in natural ponds and wells do not have separate storage facilities. Thus capital costing is thought to be conservative.

Operating costs will be favoured if there is an economy of scale. The values taken here are by reduction to an hectare cycle-time of values obtained in relatively small areas. Larger plantations are bound to reduce these values further.

In the energy calculations, total metabolic requirements have been allowed for. The energy output/input ratio will be considerably higher, if only the work-energy is accounted for.

In all calculations, standby labour and materials have been taken, so that the estimates will be on the high side.

The plantation is worked only 275 days a year, not considering weekly leave allowances. 90 days a year of rainfall or other inclement weather is unusual in these areas. However all staff is paid for these 90 days. Present practice employs only casual labour paid for strictly by head count at work spot. Weekly days off are also paid for in the present study.

(c) **Analysis of the capital cost-table, Table III:**

Land and roads form more than 80% of the costs in all cases, going upto 95.4% in the Forest Department cultural practice. In Injambakkam, water tanks cost nearly 15% of the total, due to the cultural practice of watering every day for the first season. Thus cultural practices decide the yield which in turn decides the cost of the plantation. Efficiency of land use therefore becomes imperative, especially since the land costs are such a high percentage of the total. It may be noticed from Table III that if Injambakkam planted 10 000 trees/ha, then its capital costs would be one-quarter, i.e. the same as Pondicherry with the same density of planting. Thus if the present data is reconfirmed, the soil differences are minor, when compared to the superimposed cultural differences. Also as stated in Section. 3, hexagonal planting will essentially amount to 16% more plants in the same area. It may be informative to state here that the Giant Ipil-Ipil is planted at the rate of 50 000 trees/ha in the Philippines. Madurantakam area has about twice the capital cost of Pondicherry at the same density of planting though the cultural practice is very much more energy intensive. In fact one can hazard the statement that addition of fertilizer here is counter-productive, but this statement needs to be checked very carefully before final judgement is made.

(d) **Analysis of the operating cost-tables, Tables IV to VIII:**

The major item of cost are in felling and transporting in Pondicherry. These amount to nearly 45% of the total (See Table IV). Security staff also accounts for a heavy percentage and this is true in most areas. If the workers can be persuaded to stay in the plantation, then this item can be reduced considerably. Energywise the major item is diesel fuel in Pondicherry. However the cultivation is still very efficient on energy return, yielding

a return of 97.1 units of energy for every unit of energy input. As shown later, the photosynthetic efficiency is about 1.5% here, hence for the return calculated, the value of the energy input over and above sunlight is negligible.

The Madurantakam cultural practice leads to a high percentage of costs on felling and security. In fact security staff becomes a major factor of cost as the cycle-block increases. However here the energy values are heavily skewed towards fertilizer application because synthetic fertilizer is applied. This does not result in higher yields. The energy return is also lowest here, 38.8, compared to Pondicherry, 97.1, reflecting the energy intensiveness of modern agriculture. In Injambakkam, due to the sandy soil excessive watering is necessary and this contributes a large factor of cost. But if planting density were increased, the yield would be the same as Pondicherry. Energywise, transporation and watering form more than 50% of input.

The large Forest Department areas need heavy security guard. Hence the cost is heavily loaded in favour of security staff. The costs Rs. 5353/7 years calculated here, are in the same range as calculated by the Forest Department themselves. This gives confidence in the results. Energywise the returns from Forest Department practices are very efficient: 88.1 units/unit of input.

Table VIII gives a comparative statement of all four areas.

(e) **Analysis of the returns table, Table IX :**

The returns table IX gives the pay-back period in years calculated as explained already. It can be seen that at current selling prices i.e. Rs. 200/- per tonne, Pondicherry and Madurantakam yield good profits (land will be owned at the end of the period). However Injambakkam and Forest Department never make a profit even if land is given free, but roads have to be laid. The practice in the sandy tracts is to lay palmyra leaves and water them down on the sand. This provides a very acceptable track for 10 tonne lorries. Thus no roads in the sense used here are really necessary. Injambakkam can be very profitable if there is no initial investment on land and roads. The Forest Department never

pays-back, reflecting its great inefficiency. In our conversations with Forest Department staff, it was obvious that least attention is given to plants here.

(f) Cost conclusions :

Energy Plantations are a new concept, hence the exact norms to be followed are not clear. The questions to be asked are : (a) can they compete with present thermal plants ? (b) can they use local skills and provide employment ? (c) are they ecologically safe ? The answer to all these questions seems to be an unequivocal *Yes !* The Philippines have a 75 MW plant working on Ipil-Ipil and in India, *Casuarina equisetifolia* or other hybrids seem to be the answer at least in Tamil Nadu.

The basic assumption in the first question posed in this sub-section is that power is the product and that the plantation itself should work to be a captive supplier of fuel to the power plant. In such a case, it seems very worthwhile to go in for casuarina plantations, on an intensive basis. The plant is well-adapted, adds nitrogen to the soil, is a high calorific value fuel, grows on sandy tracts and last but not least is very cost effective. If the land is free, but roads have to laid, all at one time, then by intensive methods now being practiced, a pay-back perid of 30 years is sufficient, even if the selling price is only Rs. 100/tonne and 9 % interest is compunded on all borrowings. These are very severe demands on the costing system with all its inbuiit conservative features. Thus inspite of no intercrop credits, no ash-credits, no ratooning credits, in addition to all the cost-conservativeness, the plantation seems to be viable.

An analysis of investment per-work place is useful. Not counting supervisory and managerial staff the energy plantation will employ the following number of people at a given density per hectare ; (both these values are given).

(See also Table II)

By Pondicherry standards	:	11 715 ;	1 person/hectare
Madurantakam standards	:	25 840 ;	1 person/hectare
Injambakkam standards	:	46 800 ;	1 person/hectare
Forest Department standards	:	22 740 ;	0.36 person/hectare

Table X summarises these results and includes the cost/work place for two investment decisions.

TABLE X

Place	Total hectares	Total people	Investment/work place		
			Work spots/ha	Cap. Cost/work place with land	Cap. Cost/work place not incl. land
Pondicherry	11 414	11 715	~ 1	18 042	8299
Madurantakam	28 160	25 840	~ 1	19 811	8916
Injambakkam	53 923	46 800	~ 1	23 698	12 176
Forest Department	65 999	22 740	~ 0.4	52 619	23 596

Some conclusions can be drawn from Table X. Without land costs being included, 1 person per hectare can be employed at a cost of Rs. 8299. Thus intensive cultivation of casuarina by the Pondicherry method leads to the lowest investment/work place at the same density as more primitive cultivation methods i.e. Injambakkam. However, the economy of scale-factor seems to be operating in 'number of plants/hectare', the higher the better, because plant for plant, Injambakkam yields almost as much as Pondicherry. Almost no large-scale industry will give employment for traditional skill, as this energy plantation, at such a low cost.

Ecology, energetics and land-use considerations weigh heavily in favour of the energy plantations using *Casuarina equisetifolia.* Coal yields an approximate value of 32 for output/input energy ratio, whereas these plantations vary from 40—90 for the same ratio.

(g) **General conclusions:**

Table XI compares the Giant Ipil-Ipil of the Philippines with our plantation practice. A 75 MW installed capacity plant at 70% capacity factor, is now working on this plantation. The values obtained here are comparable for the higher generation efficiency chosen here. It may be mentioned that Szego and Kemp (See Section. 1) have used 35% generation efficiency.

TABLE XI

Comparison of Giant Ipil Ipil & Casuarina

Sl. No.	Particulars	Giant Ipil-Ipil *Leucaena latisiliqua*	Casuarina *Casuarina equisetifolia*
1.	Duration in years	3 — 7	4 — 7
2.	Max. population advocated/ha (Density of population/ha)	100 000 — 400 000	10 000
3.	Calorific Value of bone dry wood	4656 kcal/kg. m	5278 kcal/kg. m
4.	% of moisture of freshly cut tree	50%	30% — 4 year-old 20% — 7 year-old
5.	Yield of bone dry matter tonnes/ha/yr.	50	43.75
6.	% of Ash	0.8%	0.7%
7.	Kg. bone dry wood/KWH at the stated efficiency of generation	0.9863 (18%)	0.56 (30%)
8.	Sq. km/MW	1.2 /MWe installed	1.1 based on 100 MWe actual

References for this Table: 1. Pancracio V. Bawagan and Jose A. Semana "Utilization of Ipil-Ipil for Wood"—Sep. 1976. FORPRIDECOM, National Science Development Board, College, Laguna, Philippines.

2. Jose A. Semana, "Energy Plantations for steam power plants", August, 1977, FORPRIDECOM, Philippines.

The Giant Ipil-Ipil, supply forage leaves for animal-feeding as well. It is hoped that *Sesbania grandiflora* (Agathi) trees whose leaves, beans and flowers are edible, will form the subject of a future study. Our experience is that growth of 5m trees in one year is quite feasible and the timber will be comparable to Giant Ipil-Ipil.

Photosynthetic Efficiency of Casuarina:

The photosynthetic efficiency is calculated as the ratio of the energy contained in the bio-mass, to the energy available from the sun.

Sample calculation for Pondicherry yield:

The average solar insolation in India is 12.5 $kcal/cm^2/mth$.

(Ref: V. G. Bhide "Solar Energy Utilization in India & Abroad", 'Seminar Proceedings: Industrial Application of Solar Energy'-Madras, June-1975, published by NPC, Lodi Road, New Delhi-110 003.)

Energy contained in Bio-mass/ha/4 years

= 250 t/ha x 1000 kg/t x 3700 kcal/kg (at 30% moisture in wood).

Photosynthetic Efficiency = 250 t/ha x 1000kg/t x 3700 kcal/kg ÷ 12.5 $kcal/cm^2/mth$ x 10^8 cm^2/ha x 12 mth/yr x 4 yrs = 1.54%.

The photosynthetic efficiency of Madurantakam yield is 0.616%, that of Injambakkam is 0.3% and goes down to 0.25 % for that of Forest Department yield.

These efficiencies can be considerably enhanced by intercropping. Thus a casuarina forest can be progressively used for energy as well as for enriching the land.

Approximately 110 hectares of casuarina for 100 MWe actual, or 1.1 square kilometre are needed per megawatt in the best cultivation techniques. This is equivalent to generating about 880 000 000 KWH or 880 million units per year using a forest area of

10 kilometres by 11 kilometres. This can be done in perpetuity. Another way of saying this is that, Tamil Nadu generates about 2100 million units a year. Roughly a third of this can be done in perpetuity by using a 11 km square casuarina forest on waste land.

SECTION. 6 : SUMMARY OF CONCLUSIONS

1. Using cultural practices in Pondicherry, Madurantakam, Injambakkam and Forest Department areas, costs and energy analysis have been undertaken for setting up a 160 MWe (100MWe average) power plant burning fuel-wood from the casuarina tree.

2. The Pondicherry method using 10 000 trees/ha and yielding upto 300 tonnes/ha-4 years seems to be the best for this purpose. 1.1 square kilometres are required per Megawatt. The plantation will employ about 11 000 agricultural labourers.

3. Using this method and depending upon certain investment decisions, the plantation will pay-back all capital and other costs in periods varying from 5—30 years. At the end of the larger periods, land becomes wholly owned by the plantation. The plantation can replace coal burnt power.

4. Other methods have varied degress of success or do not result in viable commercial ventures.

5. The energy returns are always favourable. Ecologically these plantations are far more desirable than present thermal power plants.

6. The use of intensive forestry of casuarina renders many benefits to the soil. Some recommendations are given for improving certain aspects of forestry practice.

7. These plantations offer a way to generate small amounts of decentralized power for rural use.